SILICON MONOXIDE-SILICATE INTERACTIONS EXPLAIN OXYGEN ISOTOPE VARIATION OF ROCKY INNER PLANETARY BODIES

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Introduction: It has long been realized that the enstatite chondrites are one of the most plausible primitive precursor materials of the Earth and other rocky planetary bodies. Oxygen isotopes of chondrules record distinct characteristics of the localized nebular environment, thus they are considered a key tracer of the nebular conditions at which planetesimal precursors formed during the earliest stages of the protoplanetary disk. Oxygen isotopic compositions for most of the bulk enstatite and enstatite chondrite chondrules resemble those of the Earth and Moon, clustered around the terrestrial fractionation line (TFL). Although these data show no clear trend on the three-oxygen isotope diagram, they have been interpreted as the result of mixing processes between precursors solids including ^{16}O-rich components and nebular gas with oxygen isotopic compositions near the TFL. However, yet uncertain are the physical and chemical parameters for the chondrule formation process. Oxygen isotopic compositions of individual chondrule measured by high-precision (i.e. fluorination) methods were, however, only reported from three EH chondrites in the 1980s to early 1990s [1-3]. In this study, we report new and systematic oxygen isotopic compositions of chondrules separated from various types of enstatite chondrites using a highly precise and accurate methods, then discussed their origin and the role for the formation of terrestrial planets [4].

Samples and Method: The samples analyzed in this study were Sahara 97103 (EH3), Yamato 691 (EH3), Indarch (EH4), Yamato 74370 (EH4), Yamato 79810 (EH4), Asuka 881475 (EH5), St. Mark's (EH5), Yamato 980223 (EH6), NWA 1222 (EL5), Eagle (EL6), and Hvittis (EL6). Chondrules and enstatite-rich fragments were separated from these meteorites, followed by acid-leaching to remove the surface contamination. Chondrules of >0.3 mg were selected for the single chondrule analysis and chondrules of <0.3 mg were combined for analyses of composite chondrules. The extraction of oxygen was performed by laser fluorination method and the isotope ratios in the extracted oxygen were determined using a Thermo MAT253 gas source mass spectrometer in dual inlet mode [5]. The internal precision of San Carlos olivine (MSOL-1) during the analyses was obtained as $\delta^{17}O = 2.754 \pm 0.035$ ‰, $\delta^{18}O = 5.288 \pm 0.072$ ‰, and $\Delta^{17}O = 0.004 \pm 0.009$ ‰ (1SD, N = 39).

Results and Discussion: We report $\delta^{17}O$ and $\delta^{18}O$ values of 80 fractions of chondrules and enstatite-rich fragments separated from 11 enstatite chondrites. The $\delta^{18}O$ values of chondrules and enstatites range between 5.0 and 6.0 ‰ which is much narrower than the reported range of bulk enstatite chondrites and of chondrule minerals. Enstatite-rich chondrules in EH3 and EH4 show a wider range of $\Delta^{17}O$ values (1.3 ‰) than that of bulk enstatite chondrites data, and they show a linear trend with a slope of 1.27 on the three-oxygen isotope diagram. This steep slope, greater than unity, is distinct from any known three-oxygen-isotope trend for chondrites, suggesting unique formation process for enstatite chondrite chondrules. On the contrary, chondrules in EH5 and enstatite in EH6, EL5, and EL6 show smaller variations in $\Delta^{17}O$ values (0.13 ‰), which are similar with the bulk enstatite chondrite. This suggests that the oxygen isotopes of chondrules and enstatites in type 5 and 6 enstatite chondrites progressively approached equilibrium during thermal metamorphism. A silica-rich chondrule (SRC) show distinct oxygen isotopic composition, with greater $\delta^{18}O$ (6.83‰) and high $\Delta^{17}O$ (0.340‰) relative to values for the enstatite-rich chondrules and enstatites. Petrography and the inferred crystallization path demonstrate that the SRC was a completely molten droplet which have been formed via reaction of molten Mg-rich chondrule with SiO vapor under high temperature conditions at >~1960K [6,7]. Evaporation-driven open-system gas–melt interaction model [8] revealed that a unique three-oxygen isotopic trend for EH3 and EH4 chondrules can be explained by reactions between SiO gas and silicate melt in the early solar nebula. The low dust/gas environment during reaction is consistent to explain the highly reduced condition evidenced by mineralogy and the low FeO contents in enstatite. This result show that the combination of dust evaporation and olivine-SiO interaction at elevated temperature which may have occurred before chondrite accretion could produce the oxygen isotope variations of precursor materials of the differentiated meteorites, Earth, and Moon. Over the same period, accretion of parental bodies of achondrite and terrestrial planets, followed by whole body melting, could have proceeded in the same region. We infer that the variation in the oxygen isotopic compositions of enstatite chondrite chondrules could reflect the decreased oxygen fugacity caused by the removal of H_2O from the inner protoplanetary disk and increasing SiO that occurred within a few Myrs after the formation of Solar system.

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